The Internet: Beyond Earth Orbit

Interplanetary Networking for Advanced Robotic and Human Missions

Steve Braham

NASA Haughton-Mars Project Canadian PI and Chief Field Engineer

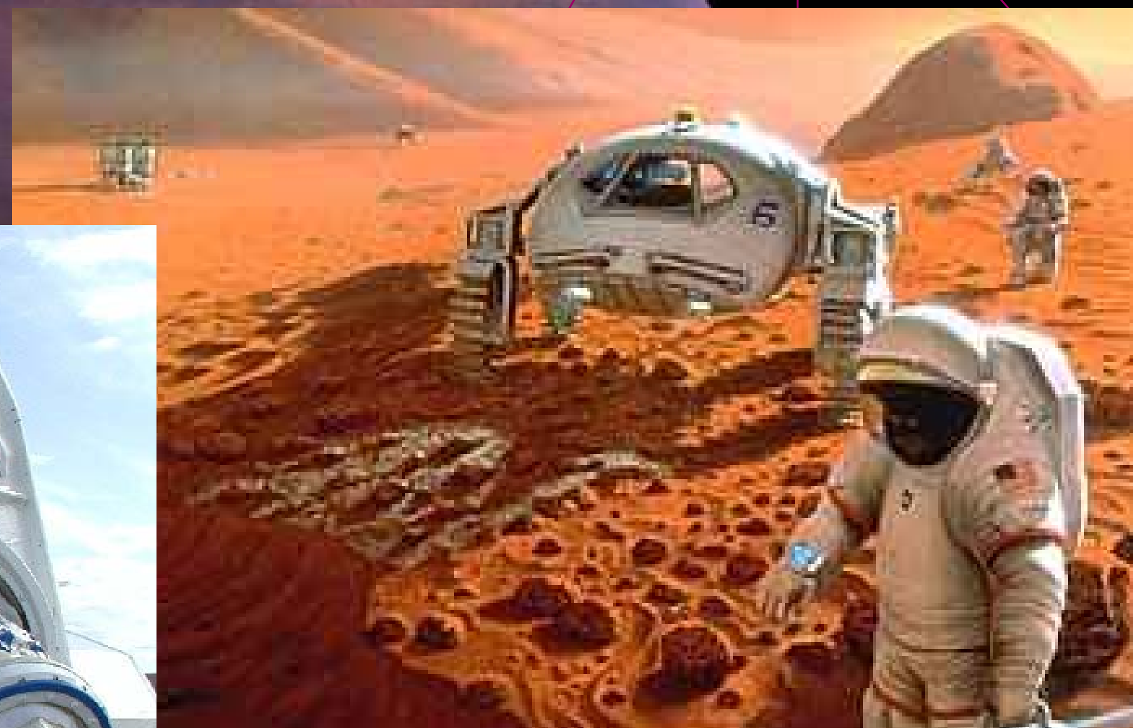
Senior Researcher, CSA MarsCanada, Telematics Research Lab, Simon Fraser University, Canada

Peter Anderson (CSA MarsCanada PI, Director SFU TRL)

Pascal Lee (NASA HMP PI, NASA Ames, SETI Institute, Mars Institute)

Brian Glass (NASA HMP Chief Engineer, NASA Ames)

Taking the Internet Beyond Earth Orbit



Pure IP, the Space Internet, and Integration

IP in Deep Space

- IP provides a platform capable of integrating many space communications needs
  - Deep Space Networking
  - DSN to researcher
  - Planetary orbital packet relaying and routing
  - On-board spacecraft systems (human and robotic), constellations, formations
  - Surface wireless communications
- Integration highly driven by IETF, IEEE, and other standards process
  - Integration maximized by not using a single fix or protocol
  - Relays, DSN systems, etc, must move away from store-and-forward methodologies to increase protocol pass-thru.
- If done, promises:
  - Reduced costs, increased stability
  - Standard, and lack of store and forward, allows international collaboration and buy-in

Issues in Deep Space

- Latency
  - Means some protocols won't work for certain applications
  - Not a reason not to use other IP protocols where they work
  - Real-time (continuous) still important for many reasons – another problem with store and forward
- Weak signals
  - Drives to high BER and packet loss
  - Not all applications need a low packet loss
  - Not a reason to choose low packet loss protocols for everything

SFU PolyLAB (a TRL unit): Connected Human Intelligence in Space Exploration

- Issues for Human Spaceflight Communications:
  - Extensive communication required for scientific field exploration
  - Mission operations requires complex modalities in Human missions
  - Purely robotic comms/traditional spacecraft solutions don't work for Human Missions

PolyLAB Deep Space, Planning, Operations, Computing and Communications

- Systems in field that fully emulates effect of Earth-Mars IP communication link, including delay and packet loss
- Use normal mail client protocols (IMAP, POP3) to deliver and read mail on local mail servers.
- Use a special but standard UDP-based (MDPv2) protocol to move messages between “Earth and Mars”. Recently tested by NASA Goddard on STS-107.
- Video, Audio, Real-time Telemetry: use conventional UDP protocols, instead of IPN/SCPS robotics-oriented protocols. More appropriate to Human Missions.
- Open to whatever file transfer protocols meet application needs (and there’s not just one file transfer need)

CSA MarsCanada: Internet Beyond Earth Orbit

- Supports Mars analogue research in Canada
- Developing new planetary exploration communications and computing systems, significantly in advance of other space agencies' systems.
- Test in a hostile, Mars-like, environment
- Driven by the the exploration process of Humans, sometimes aided by robotics. Driven by their requirements.

NASA Haughton-Mars Project

- International collaboration: CSA/NASA/SFU/CRC/SETI Institute/Mars Institute.
- HMP PI: Pascal Lee (NASA/SETI Institute/Mars Institute)
- Canadian High Arctic.
  - Twenty km Crater, 23 Mya
  - Mars-like!
- Exploration technology studies, Humans on Mars focus
- Biggest Mars Analog exploration project in the world – roughly 150 researchers per year involved. Large press coverage.
- Field Engineering Management by SFU and CSA MarsCanada.

Mars, on Devon Island

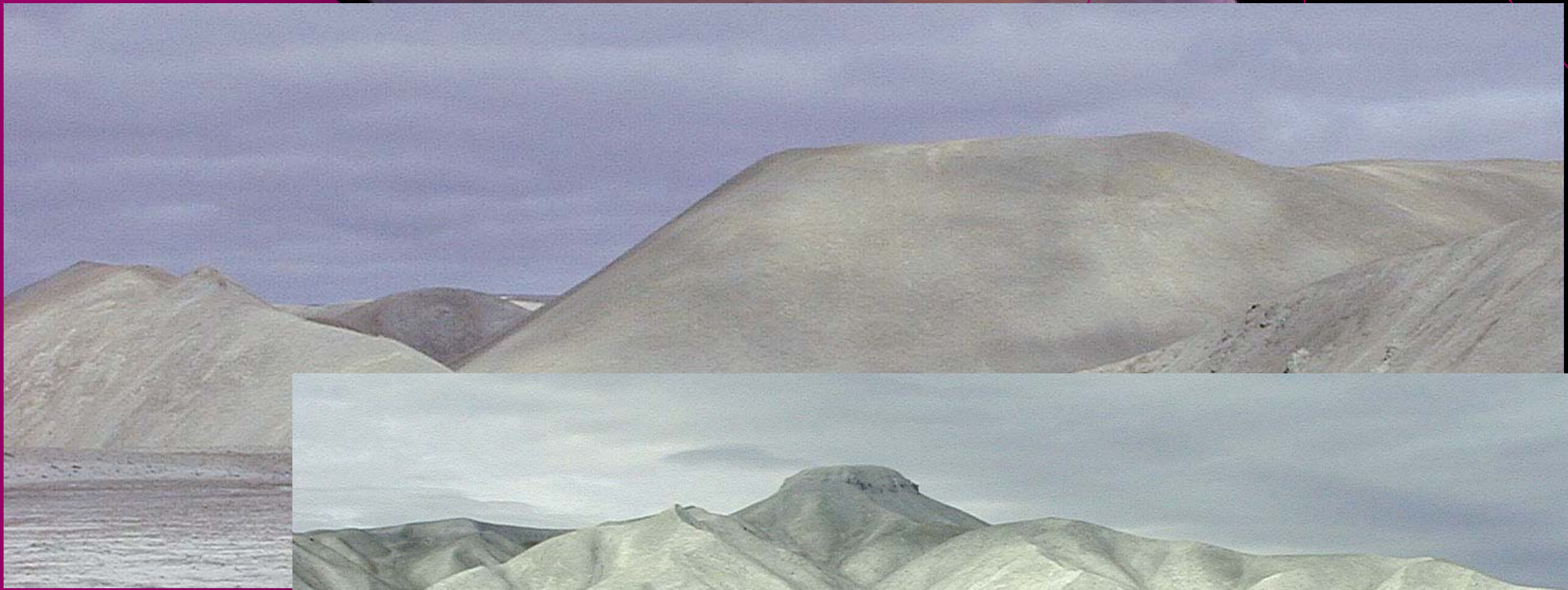
- Canadian High Arctic
- Twenty km Crater, 23 Mya
- Hostile, permafrost, barren, bears
- Mars-like!
- Astrobiology
- Geology
- Exploration technology studies
- Biggest Mars Analog exploration project in the world – roughly 150 researchers per year
- Field Engineering Management by SFU and CSA MarsCanada

HMP Exploration Technology Studies

- Robotics
- Telemedicine
- Mission Control
- Field operations
- Internal spacecraft comms and computing
- Spacesuit comms and computing
- System security, robustness, interoperability

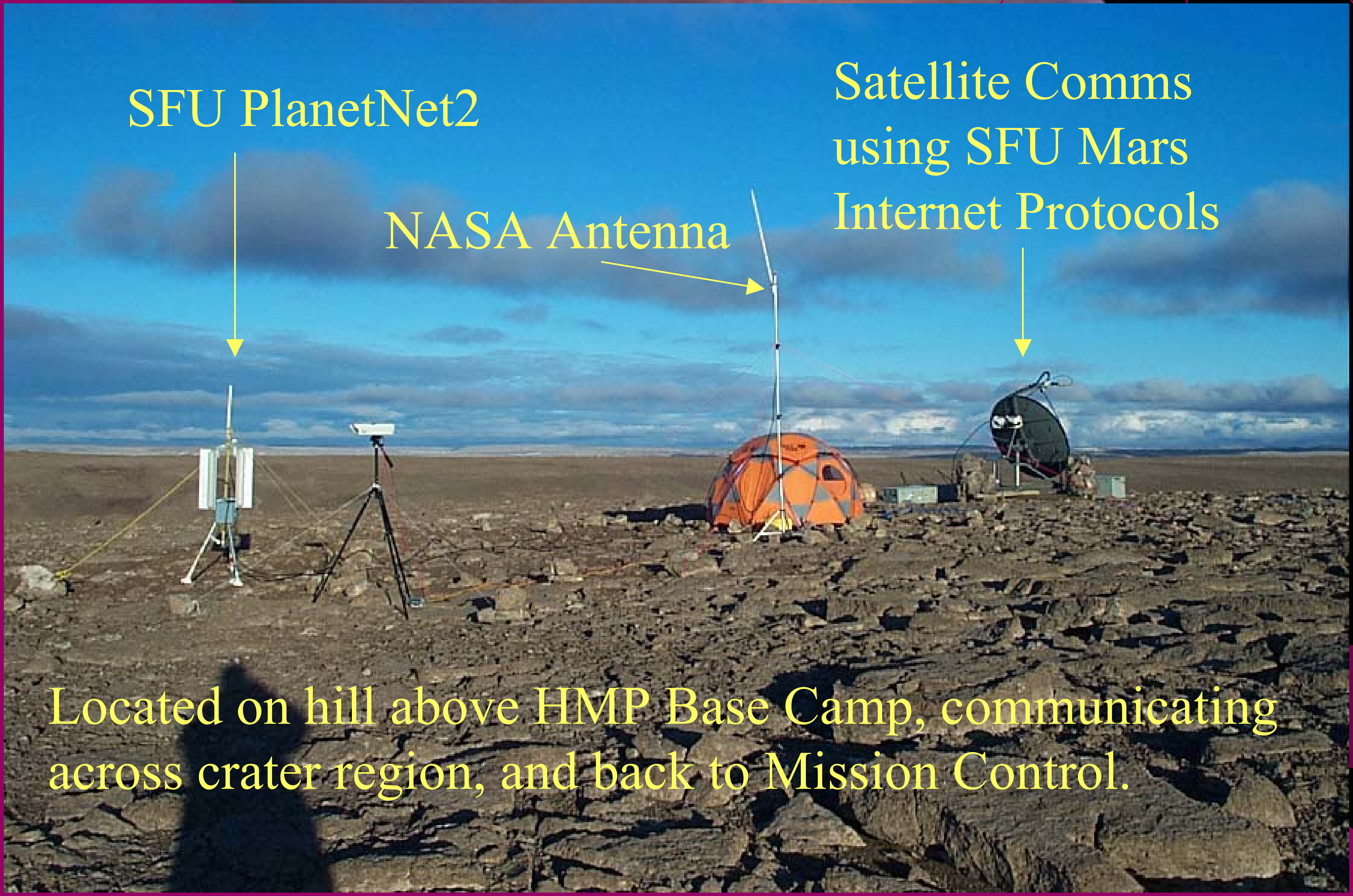
Mars-like Terrain on Devon Island!

Moon-like, too




Arthur Clark Mars
Greenhouse
Shower(!)
Kitchen Tent
Exploration Technology
Research Tent
Pee Drums (you don’t want to know)
Poop Tents (you REALLY don’t want to know)
Us (we don’t want to be bear food)

Radio/SatCom Integrated via IP



Inside the Planetnet Uplink Facility: IP Integrated

Telemetry and Robotics

- Return of data from remote instruments via IP
- GPS Data via IP
- Command and Control via IP
- Potential NASA Scout Mission development using IP

Mobile!

Communications from military and other vehicles: Complex modalities, IP integrated

The problems with TCP/IP: Conventional Internet

- TCP/IP waits for signals to come back to decide if packets are being lost.
- Waits a certain amount of time - time designed for standard networks.
- Assumes any problems with lost packets are due to congestion (too many packets), and slows down!

Solutions: Internet is not the same as TCP/IP

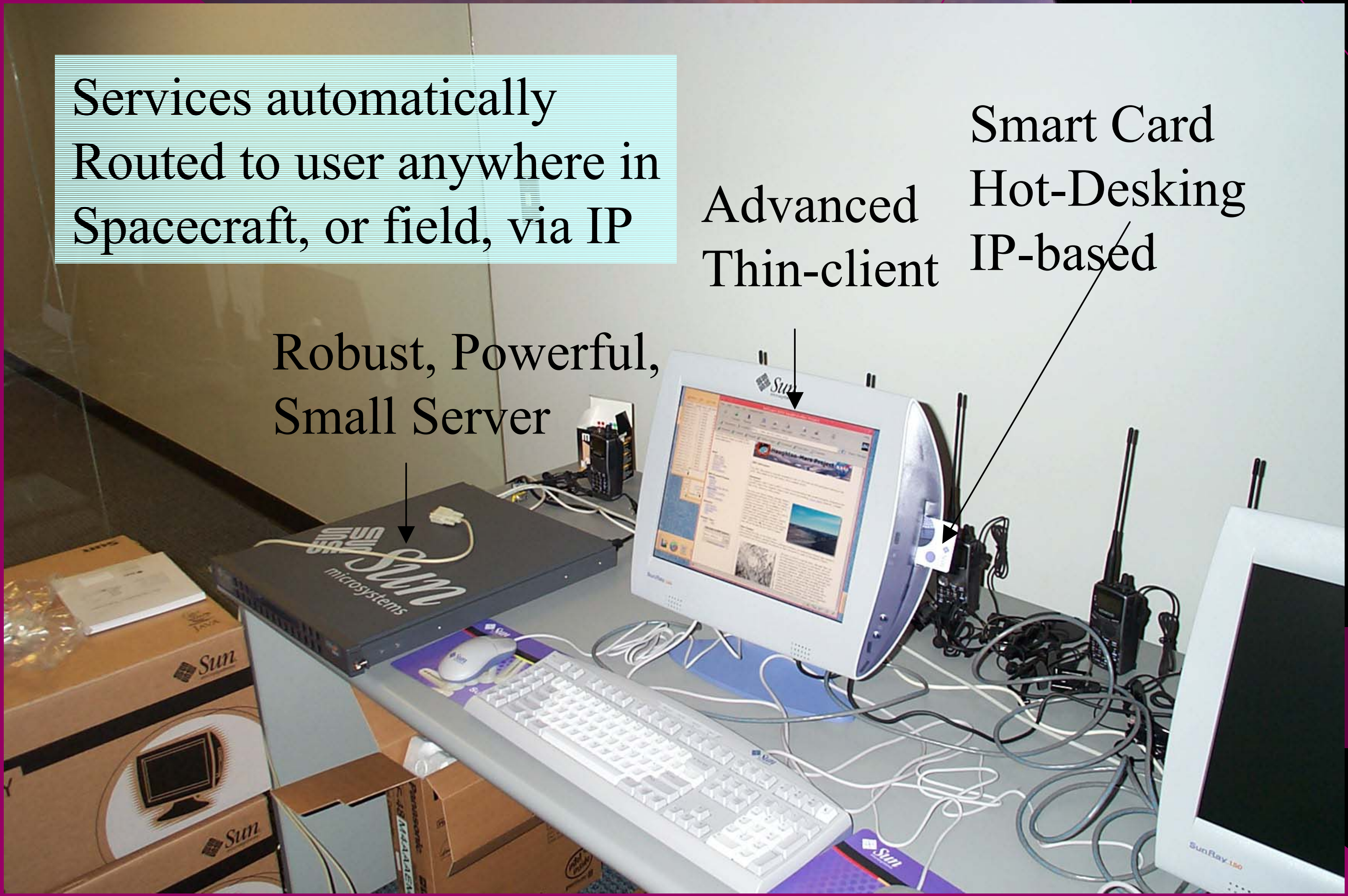
- Don't use TCP/IP -- UDP (constant streaming) for video is used a lot, even on the Internet.
- MDP – UDP/IP protocol for file transfer across long-delay networks (US Navy, UN, US Post Office)
- CFDP can work over UDP. Good for different applications.

- Finding the best protocols to support different applications
- Developing a focus on long-term needs, and the requirements for advanced robotic and Human missions.
- Store and forward fixes protocols. BAD THING.

The Problem with SCPS: Why we've moved away from it.

- Solution without a problem – present *appropriate* IP-based solutions perform within required performance levels for interplanetary missions
- Solution without a research community – professional research is IP, ATM, and other industrial solution performance. Thousands of new researchers graduated per year.
- Solution without a quality implementation – Lots of great researchers but proprietary solutions will never have the same implementation quality as IPv4 and IPv6 stacks. For every packet that goes through a Space Internet, a billion will go through the conventional Internet, with standard transfer protocols. Deep analysis and understanding.
- Solution without compatibility – IP-based solutions designed around performance-based interoperability. SCPS, even in interfacing to IP-based solutions, does not play the game of appropriate network behaviour. Looking like TCP/IP doesn't count.
- BUT: Great concepts, and a lot has been learned. CFDP still a great option, over UDP. But we need to move on and keep with the times.

XANTHE: Computing for Mars using IP



Operations Centre on Mars: HMP Base Camp: XANTHE Uses MDPv2 for Files

Global Communication: HMP<->NASA JSC and Ames: UDP video and audio

Spacesuit Exploration Support Computer

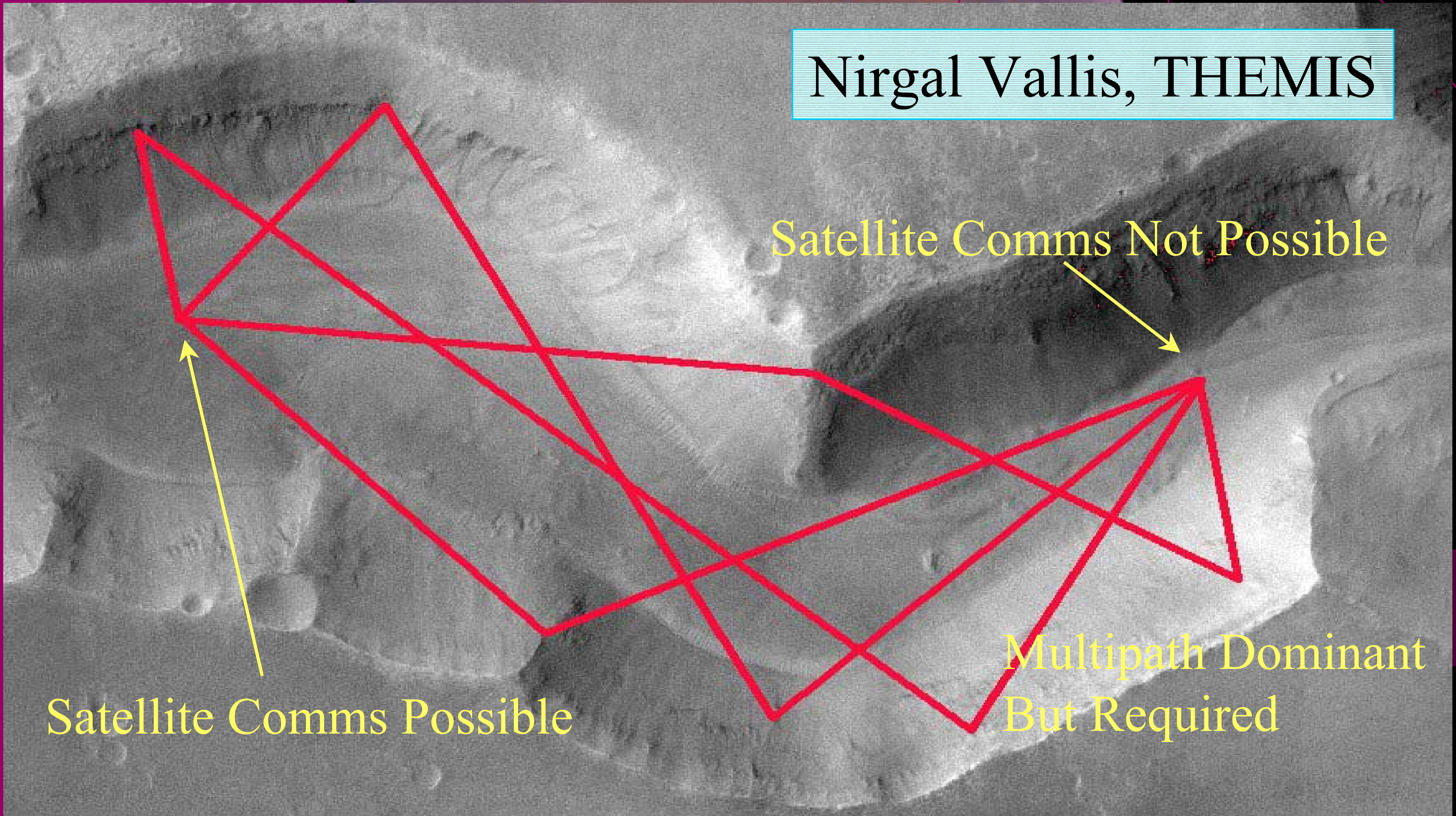
Head-mounted Display, advanced Wearable computer

- GIS, GPS
- Next-generation voice control
- Wireless interface to regional network and spacecraft computers
- Remote command and control
- All Integrated with pure IP

Application layer

- Database access: access and update of information.
- XML standards/translation services
- Distributed computing
- Voice input and output
- Regional, space, network management
- All well supported by UDP and ATM, and IP in local field environment

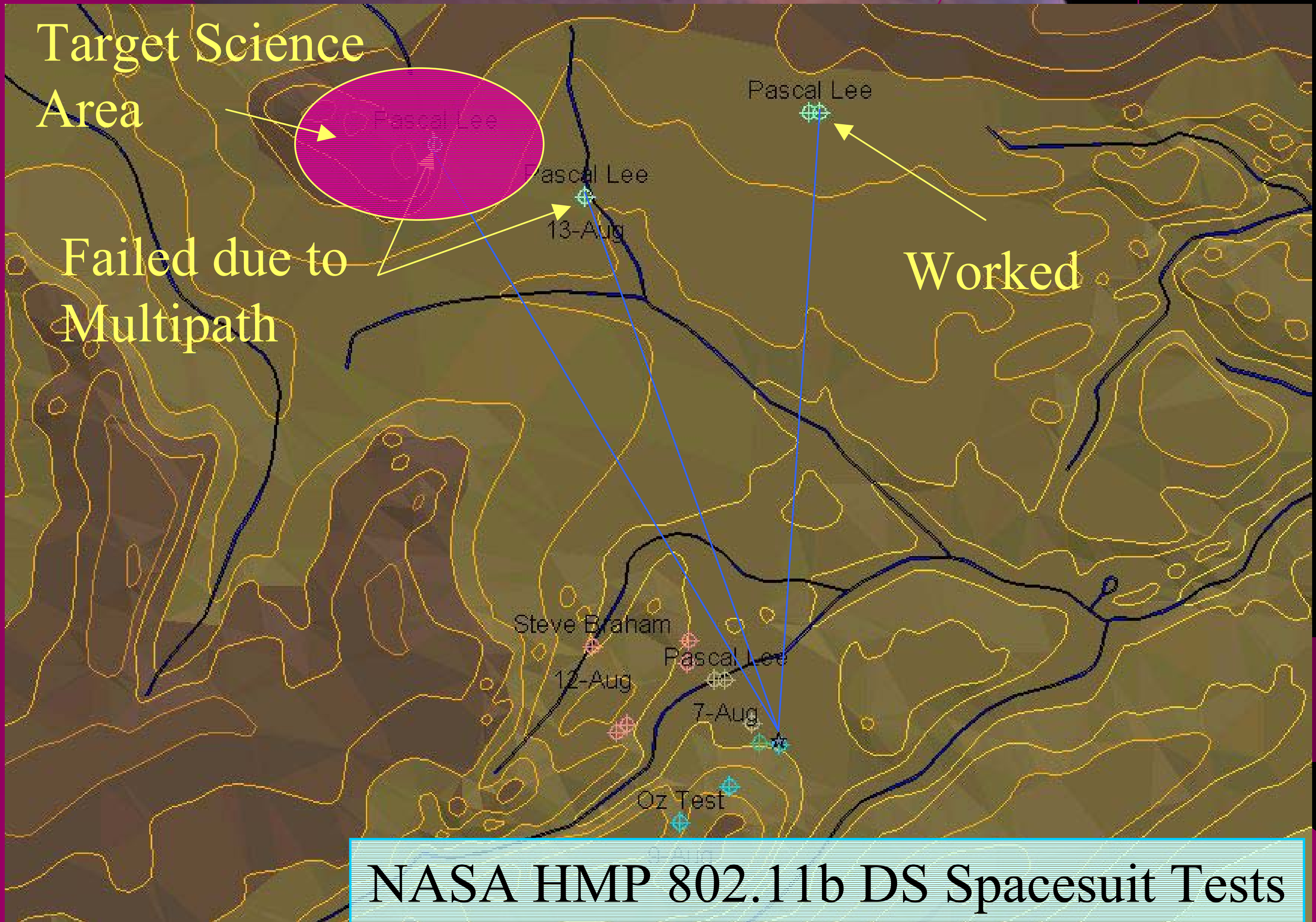
Getting to the Science Around the Bend



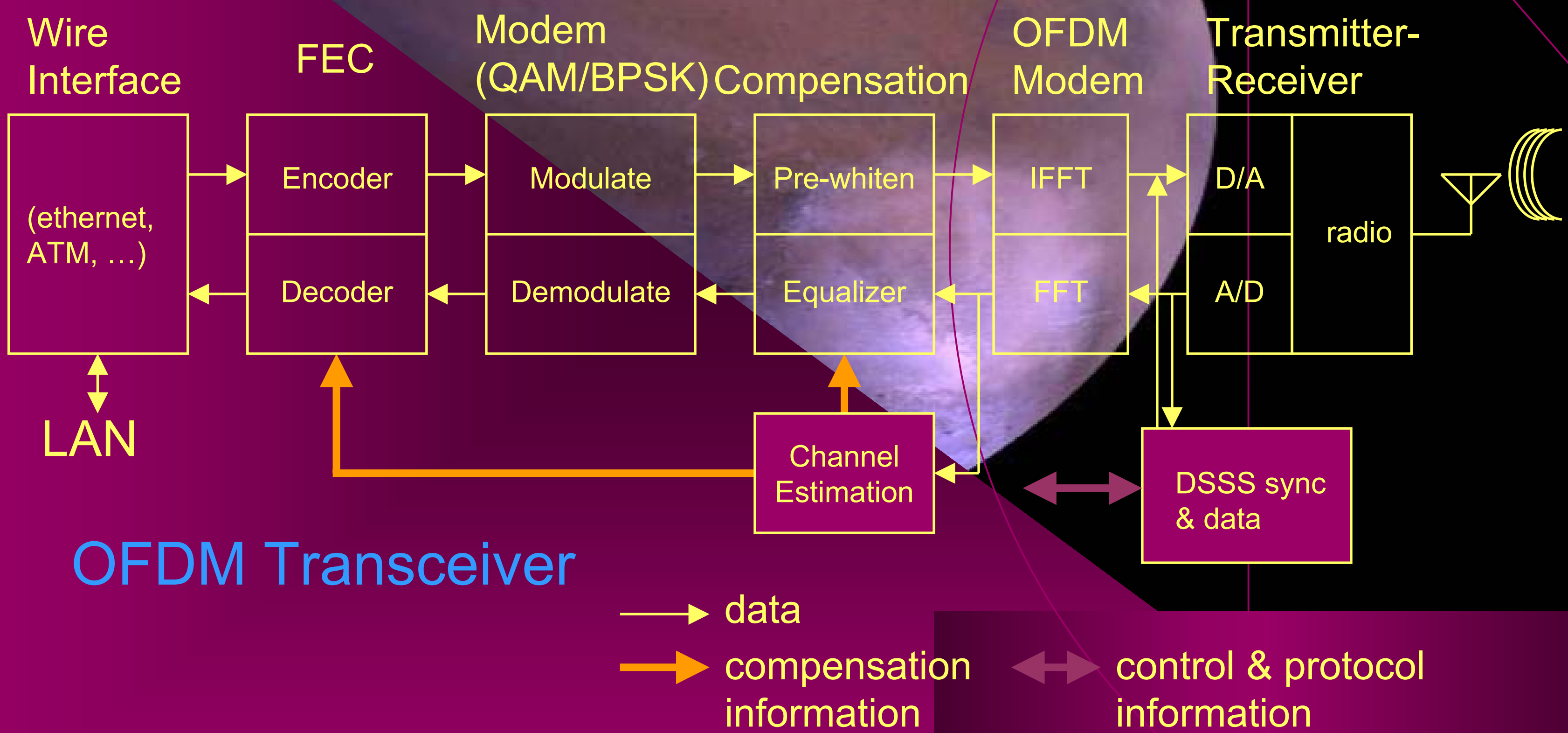
IP-based Radio Technology

- IEEE 802.11b DS: spread spectrum single-carrier
- PlanetNet 1: Spread spectrum, but each “symbol” is coded for advanced multipath behaviour.
- Orthogonal Frequency Division Multiplexing: advanced 4th generation wireless comms. Data transmitted over multiple frequencies simultaneously
  - IEEE 802.11a and 802.11g: Baby OFDM, with 52 carriers
  - PlanetNet 2: Large-scale OFDM, with 256 carriers, symbol coding, and sophisticated signal processing. Can operate out of line of sight, and not CSMA/CD-based, so high-performance in large latency and multipath environments. Exploration region. Best performance.
- All IP COTS techniques, with billions of dollars of R&D investment behind them. Not something we should repeat for proprietary protocols.
- Many more wireless comms options needed than DSN options. Must not let latter drive former.

Not all COTS work: 802.11b Not For Mars!



W-OFDM system: Not something we want to redo as a special CCSDS standard

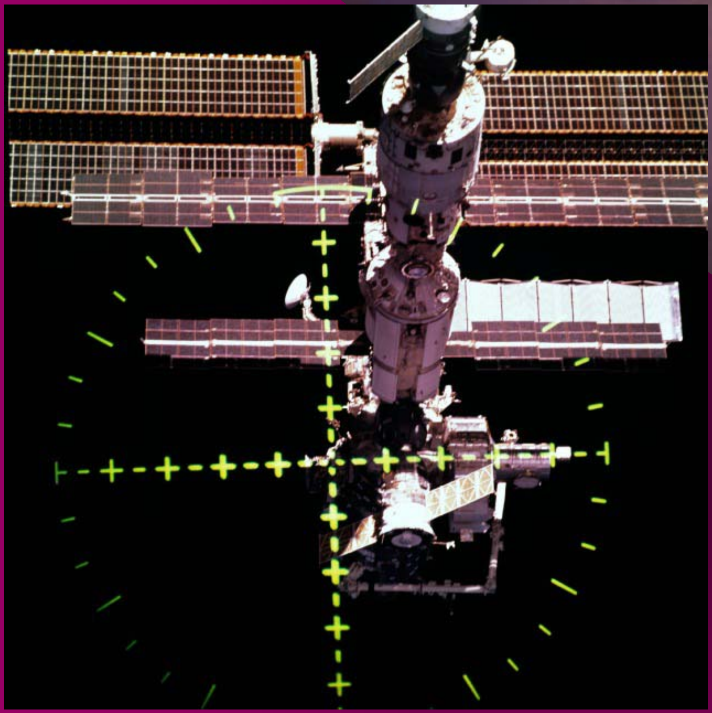


Emerging FPGAs make such advanced systems increasingly possible to implement for Deep Space Environment

IEEE IP Standards Moving Fast

- Java 1.4 supports IPv6, SSL, Kerberos, UDP Multicast
- IEEE 802.16 new emerging standard for long-range, non-line-of-sight comms in high multipath environments, utilizes IP over OFDM. QOS.
- DVB-RCS: emerging standard for satellite networking, utilizing IP for customer level, and ATM-based and/or IP-based S/C processing
- Magnitudes more funding in COTS and near-COTS WLAN Research than entire NASA R&D Comms Research budget
- Ditto for IP Routing, Mobile IP, IPv6, Distributed Computing via IP
- Ditto for commercial IP over Satcom
- MarsCanada deploys COTS IP technologies already roughly EIGHT MAGNITUDES better in performance than expected Proximity-1 type CCSDS technologies in Mars-like multipath environment (300 times data rate, 300,000 times surface area coverage, for given power). *Increasing in performance.*
- **CCSDS via proprietary NASA standards will never catch up, or be compatible with advanced COTS technologies**

Wireless Computing In and Outside Large Spacecraft



Reflections from structure may require next-generation wireless IP technologies

Conclusions

- Time to take the Internet BEO!
- Appropriate use of COTS or proprietary communication solutions requires understanding of planetary exploration field environment through actual long-range traversing missions and analog field studies.
- Integrated systems studies, such as NASA HMP and CSA MarsCanada, required to determine appropriate network protocols and application layers. Testing defines solutions.
- Present proprietary CCSDS Standards not appropriate for advanced planetary exploration missions, but concepts important.
- Emerging IEEE and IETF standards-based IP solutions steadily reaching and surpassing performance levels required.

- **CCSDS should evolve to reach, and utilize, industry standards for advanced regional communications. Move to an industry-standard based approach instead of proprietary solution. Then a new CCSDS can take a Space Internet Beyond Earth Orbit!**